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How does the dietary cottonseed hull affect the carcass characteristics and meat quality of young bulls finished in a high-concentrate diet?

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ABSTRACT. This study evaluated the effects of diets composed by cottonseed hull and meat aging on carcass characteristics and meat quality from young bulls fed on a high-concentrate system. Thirty crossbred bulls were assigned in a complete randomized experimental factorial design with three diets (CH21: cottonseed hull 210 g kg^{-1}on a DM basis, CH27: cottonseed hull 270 g kg^{-1}on a DM basis and CH33: cottonseed hull 330 g kg^{-1}on a DM basis) and different aging times (24 hours and 3, 7 and 14 days). Meat from CH27 diets presented smaller *LM* moisture content ($p < 0.05$). Total lipids were smaller in CH33 diet ($p < 0.05$). At 24 hours, CH21 diet presented smaller *LM* cooking loss than other diets. The increasing aging time reduced the shear force ($p < 0.001$) on the *LM*. Meat from CH27 diet presented the highest luminosity ($p < 0.05$) and yellowness values ($p < 0.001$). Three or seven aging days presented smaller values of *LM* luminosity. Likewise, the increasing aging time presented greater ($p < 0.05$) yellowness within the *LM*. Lipid oxidation was lower from CH21 diet ($p < 0.001$). The fatty acid composition on *LM* was similar among diets. The use of cottonseed hull could be useful strategies to improve the meat quality and lean beef production.

Keywords: alternative foods, co-products, feedlot, high-grain, young bulls.

Como a casca de algodão influencia as características da carcaça e a qualidade de carne de bovinos precoces alimentados com dietas de alto teor de concentrado?

RESUMO. Esse estudo avaliou os efeitos de dietas com casca de algodão e maturação da carne sobre as características de carcaça e a qualidade de carne de bovinos precoces alimentados com dietas de alto teor de concentrado. Trinta bovinos cruzados foram distribuídos em esquema fatorial em três dietas (CH21: 210 g kg^{-1} de casca de algodão na MS da dieta; CH27: 270 g kg^{-1} de casca de algodão na MS da dieta e CH33: 330 g kg^{-1} de casca de algodão na MS da dieta) e diferentes tempos de maturação (24h; 3, 7 e 14 dias). A dieta CH27 apresentou menor teor de umidade na carne ($p < 0,05$). Os lipídios totais foram menores na dieta CH33 ($p < 0,05$). Após 24h, a dieta CH21 mostrou menor perda por cocção no *ML*. O aumento no tempo de maturação reduziu a força de cisalhamento ($p < 0,001$) do *ML*. A dieta CH27 apresentou maior luminosidade ($p < 0,05$) e intensidade de amarelo ($p < 0,001$). Três ou sete dias de maturação proporcionaram menores valores de luminosidade no *ML*. O crescente tempo de maturação apresentou maior ($p < 0,05$) intensidade de amarelo no *ML*. A oxidação de lipídios foi menor na dieta CH21 ($p < 0,001$). A composição de ácidos graxos foi semelhante entre as dietas. O uso da casca de algodão em dietas de alto de alto teor de concentrado pode ser uma estratégia útil para melhorar a produção de carne magra e a qualidade de carne de bovinos.

Palavras-chave: alimento alternativo, coprodutos, confinamento, alto-grão, bovinos precoces.

Introduction

Beef production and meat quality are influenced by nutritional contents, feeding systems, gender and animal age (Rotta et al., 2009). Brazilian beef production is essentially based on a pasture system, which may increase the slaughter age and affect the meat quality. Nowadays, the Brazilian market has been shifted toward the production of lean beef following market requirements. Currently, the market demands a carcass with a high percentage of lean meat, and the adequate fat distribution determines the market price (Realini et al., 2013). Therefore, highly efficient productive systems should be employed to maximize the growth of beef cattle, increase the meat quality, and reduce the age of cattle at slaughter.

There has been an increase in intensive Brazilian beef cattle production systems, which is supported

by the fact that performances and meat quality are affected by this intensification (Prado et al., 2009a; Maggioni et al., 2010). Livestock production systems with a high percentage of concentrate and grains that are rich in starch and high ruminal fermentation rates can make up to 80% of such diets (González, Manteca, Calsamiglia, Schwartzkopf-Genswein, & Ferret, 2012). However, high costs of cereal grains and the scale of the Brazilian production co-products may be possible alternative feeding strategies. The utilization of co-product foods from agribusinesses may be an option in finishing young bulls in feedlots with a combination of 47 concentrate and 53% corn silage causing no damage in carcass characteristics or meat quality (Eiras et al., 2014). Likewise, the co-products from Brazilian agribusinesses could potentially be utilized in beef cattle productions in which they are fed in a high-concentrate system.

This kind of co-product is not only abundant in Brazil, but also in other countries of the world as Chine, India, USA, Pakistan, Australia (Food and Agriculture Organization [FAO], 2015) which are the main cotton producers. Consequently results and use can be extrapolated to other regions or production systems.

Therefore, the objective of the current study was to evaluate the effects of addition of different quantities of cottonseed hull on the diet on meat with several aging times from young bulls (½ Simmental vs. ½ Nellore) fed in a high-concentrate diet.

Material and methods

Local, animals, housing and diets

This experiment was approved by the Animal Science Department at the State University of Maringá. The experiment was conducted at the Rosa & Pedro Sector at the Iguatemi Experimental Farm of the State University of Maringá.

Thirty crossbred bulls (½ Simmental vs. ½ Nellore) were assigned to a randomized complete factorial design experiment composed of three diets with ten animals per group in individual pens (10 m^2 for each animal).

After a 15 day diet adaptation period, the bulls were weighed and the study was started at an average initial BW of 319 ± 12.5 kg and an average age of 11 ± 0.8 months. Body weights were recorded monthly and the intake of concentrate was recorded daily until 162 days into the experiment when the bulls reached a final BW of 481 ± 22.8 kg with an average daily gain of 1.0 ± 0.25 kg (Table 1).

Table 1. The effects of cottonseed hull diets from Brazilian agribusiness on animal performance, feed efficiency and carcass weights of young bulls fed in high-concentrate system.

Parameters	Cottonseed hull diets			SEM	p value
	CH21	CH27	CH33		
Initial age, months	10.9	11.3	10.8	0.14	0.63
Final age, months	16.3	16.7	16.2	0.14	0.63
Initial body weight, kg	318	317	318	6.09	0.77
Final body weight, kg	476	483	484	4.14	0.70
Average daily gain, kg day^{-1}	0.98	1.02	1.02	0.04	0.59
Dry matter intake, kg day^{-1}	11.0a	11.8ab	12.6b	0.15	0.03

a-b: Values with different letters in the same row are different by Tukey test. SEM: Standard error of mean. CH21: cottonseed hull 210 g kg^{-1}on a DM basis; CH27: cottonseed hull 270 g kg^{-1}on a DM basis; CH33: cottonseed hull 330 g kg^{-1}on a DM basis.

The young bulls were assigned to one of three diets composed by cottonseed hulls: CH21: cottonseed hull 210 g kg^{-1} on a DM basis, CH27: cottonseed hull 270 g kg^{-1} on a DM basis, and CH33: cottonseed hull 330 g kg^{1} on a DM basis (Table 2). The diets were formulated to be isonitrogenous and isoenergetics and to provide a weight gain of 1.0 kg day^{-1} according to the National Research Council (NRC, 2000) recommendations.

The animals were fed on diets twice a day (08:00 and 16:00 hours) to meet the adequate concentrations of nutrients(feed allowance of 11.8 kg DM of diets) for growing and finishing animals (National Research Council [NRC], 2000). The soybean hull pellets and ground corn were offered all day according to ingredient intake by animals in order to adjust the energetic level of the diets (Table 3).

Table 2. Compositions of diets

Ingredients	Cottonseed hull diets (g kg^{-1} of DM)		
	CH21	CH27	CH33
Soybean hull pellets	306	238	181
Ground corn	256	228	194
Sugarcane bagasse pellets	119	119	119
Corn gluten meal	77.9	115	147
Cottonseed hull	210	270	330
Yeast	7.53	7.53	7.53
Urea	5.07	5.07	5.07
Limestone	10.0	10.0	10.0
Mineral salt[1]	7.70	7.70	7.70

[1]Mineral salt composition (kg^{-1}): calcium, 175; phosphorus, 100; sodium, 114; selenium, 15; and magnesium, 15 g; zinc, 6.004; manganese, 1.250; copper, 1.875; iodine, 180; cobalt, 125; selenium, 30; and fluorine (maximum), 1.000 mg; CH21: cottonseed hull 210 g kg^{-1} on a DM basis; CH27: cottonseed hull 270 g kg^{-1} on a DM basis; CH33: cottonseed hull 330 g kg^{-1} on a DM basis.

Diet chemical analyses

Chemical compositions of ingredients were presented in g kg^{-1} of DM (Table 3). Dry matter was determined after oven-drying at 65°C for 24 hours and milling through a 1 mm screen (Association of Official Analytical Chemists [AOAC], 2005) – (ID 934.01). Ash content was measured by combustion

Table 3. Chemical composition of ingredients and experimental diets.

Ingredients	DM	g kg^{-1} on DM									
		Ash	OM	CP	EE	NDF	ADF	TC	NFC	Lignin	ME
Soybean hull pellets	908	52.9	947.10	123.6	18.9	660	506	804	144	70.3	8.62
Ground corn	881	20.1	979.90	102.4	41.4	134	40.8	836	702	19.2	14.7
Sugarcane bagasse pellets	923	45.4	954.60	17.4	19.9	854	552	917	25.8	117	8.58
Corn gluten meal	908	82.5	917.50	234	25.5	410	112	686	275	13.3	14.1
Cottonseed hull	908	26.9	973.10	46.7	15.3	897	589	911	14.0	111	9.20
Yeast	932	46.7	953.27	355	21.3	25.5	9.35	580	554		
Urea	980	987	12.80	2610							
Limestone	984										
Mineral salt	988	997	3.33								
Diets											
CH21	905	51.9	938	110	24.1	559	363	819	256	64.7	10.5
CH27	905	52.3	938	110	23.5	579	367	820	237	66.5	10.5
CH33	906	52.9	937	110	22.7	604	376	822	214	68.9	10.5

DM: Dry matter; OM: Organic matter; CP: Crude protein; EE: Ether extract; NDF: Neutral detergent fibre; ADF: Acid detergent fibre; TC: Total carbohydrates; NFC: Non-fibre carbohydrates; ME: Metabolizable energy (MJ kg^{-1} DM) was calculated from NRC (2000) model; CH21: cottonseed hull 210 g kg^{-1} on a DM basis; CH27: cottonseed hull 270 g kg^{-1} on a DM basis; CH33: cottonseed hull 330 g kg^{-1} on a DM basis.

at 550°C for 16 hours (AOAC, 2005) – (ID 942.05) to determine the organic matter (OM). Nitrogen concentration was determined by the Kjeldahl method (AOAC, 2005) – (ID 988.05). Following the determination of the nitrogen concentration, the CP was calculated by multiplying the N content by a factor of 6.25. Ether extract content was determined by method ID 920.39 (AOAC, 2005). Neutral detergent fiber (NDF) content was measured using alpha-amylase and was expressed inclusive of residual ash.

The acid detergent fiber (ADF) was measured by using the Association of Official Analytical Chemists (AOAC, 2005) method (ID 973.18) and was expressed inclusive of residual ash. Total carbohydrates (TC) and non-fibrous carbohydrates (NCF) were determined as the difference between TC and NDF as was reported. Metabolizable energy of feedstuffs was estimated according to NRC (2000) recommendations.

Slaughter procedure and muscle sampling

The young bulls were slaughtered according to industrial practices in Brazil at a commercial slaughterhouse 80 km from the Iguatemi Experimental Farm. To minimize pre-slaughter stress, the bulls were transported and slaughtered the next day. The animals were fasted from solids for 16 hours. On arrival at the slaughterhouse, they were kept in resting pens and were humanely harvested under Brazilian federal inspection according to the Brazilian Regulation of Industrial and Sanitary Inspection of Animal Products. Following slaughter, the carcasses were identified and chilled for 24 hours at 4°C.

After chilling, the right half of the carcass was used for the *Longissimus thoracis* and *lumborum* muscle samples (*LM*). The pH was measured by using a probe-type portable pH meter (Hanna Instruments, Woonsocket, RI, USA) in the 12th and 13th ribs. The *LM* was excised between the 6th and 13th ribs for further laboratory analysis.

Evaluation of carcass characteristics

The whole-carcass composition was assessed from carcass measurements and rib composition. The 6th rib from the right half of the carcass was weighed and dissected into muscle, fat (intramuscular and subcutaneous), bone, and other tissues. The carcass compositions were calculated as a percentage of the raw weight of the 6th rib and the weight of dissected compounds (Robelin & Geay, 1975).

Subcutaneous fat thickness (mm) was measured with digital callipers and was averaged over three points.

The *LM* samples from the 7th and 13th ribs were sectioned into steaks with a 2.5 cm thickness and were individually vacuum packaged and frozen at –18°C (24 hours aging time group). The aging time group was placed in a refrigerator at a temperature of 2ºC for a period of 3, 7, or 14 days and after was frozen at –18°C further analysis.

Chemical composition

The chemical compositions of the *LM* (moisture, ash, crude protein, total lipids, and collagen) were determined by using a 200 g sample that was thawed at 4°C for 16 hours, homogenized, and then analysed in triplicates by near-infrared spectroscopy (Foss NIR Systems, Inc., USA).

Water holding capacity

Determination of drip loss was calculated from the difference in the raw weight of the *LM* samples and the weight after 24 hours. The *LM* samples were weighed, placed in netting, and suspended in

plastic containers for a period of 24 hours at a temperature of 4ºC. Drip loss was expressed as a percentage of the *LM* initial weight (Honikel, 1998).

For thawing loss, the *LM* samples were individually vacuum packaged and frozen at –18°C. Frozen samples were thawed at 4°C for 16 hours. Thawing loss was calculated as a percentage of weight loss before and after thawing.

LM cooking loss was determined by using a *LM* sample that was thawed in a pre-heated grill at 170°C and monitored with a penetration thermocouple until the internal temperature reached 72°C. *LM* samples were left to chill at room temperature and were weighed when the steak temperature reached 20°C. Cooking loss was calculated from the difference in the thawed weight of the *LM* samples and cooked steaks and was expressed as a percentage of the initial weight.

Warner-Bratzler shear force (WBSF)

The *LM* samples were thawed and cooked in a pre-heated grill at 170°C and monitored with a penetration thermocouple until the internal temperature reached 72°C. The *LM* samples were divided into eight sub-samples, each one measuring 2.5 long and 1.0 cm in diameter. A Warner-Bratzler shear blade was used to measure shear force perpendicularly to the muscular fiber orientation, according to the principles of Honikel (1998). These cores were sheared by using a Warner-Bratzler probe attached to a TA-TX2i texture analyser (Stable Micro System, Surrey, United Kingdom) set at a speed of 20 cm min^{-1}.

Instrumental color

Thawed *LM* samples were removed from the vacuum packaging and were allowed to bloom for 30 min. CIE L★ (lightness), a★ (redness), and b★ (yellowness) values were measured on the surface at three random locations using a Minolta CR-400 colorimeter (Konica Minolta Sensing, Osaka, Japan) with illuminant C, an 8 mm aperture, and a 2° observer angle.

Lipid oxidation (TBARS)

The extent of lipid oxidation of the *LM* samples was assessed by measuring thiobarbituric acid-reacting substances (TBARS) by using the method described by Botsoglou et al. (1994). The *LM* samples were thawed at 4°C for 16 hours, homogenized by Ultra-Turrax (90 s, 20000 rpm; Fisher Scientific, Loughborough, UK), and were analysed in triplicate. TBARS were expressed as mg malonaldehydekg^{-1} of raw meat.

Fatty acid composition

The *LM* fatty acids compositions were obtained by triacylglycerine methylation according to the ISO-R-5509 (1978) method. Fatty acid methyl esters (Fame) were analysed in a gas chromatograph (Varian, Walnut Creek, USA), equipped with a flame ionization detector and a fused silica capillary column CP-7420 (100 m, 0.25 mm, and 0.39 μmo days, Varian, Walnut Creek, USA) Select Fame. The column temperature was programmed at 165°C for 18 min, 180°C (30°C min^{-1}) for 22 min, and 240°C (15°C min^{-1}) for 30 min with 45-psi of pressure. The injector and detector were kept at 220 and 245°C, respectively. Gas flows (White Martins, São Paulo State, Brazil) were 1.4 for carrier gas (H_2); 30 for make-up gas (N_2); and 30 and 300 mL min^{-1} for H_2 and synthetic flame gas, respectively. The sample was injected by using a split mode 180^{-1}. Fatty acids (FA) were identified by comparing the relative retention time of FAME peaks of the samples with standard Fame 189-19 from Sigma Company, St Louis, USA by spiking the samples with the standard. The peak areas were determined by using Star software (Varian, Walnut Creek, USA).

Statistical analyses

Data were analysed by using the GLM procedure of Statistical Analysis System (SAS, 2004) to perform a randomized complete factorial design experiment with three diets and four meat aging times. The model included the fixed effects of cottonseed hull diets (CH21, CH27, and CH33), aging time (24 hours, 3, 7, and 14 aging days), and their interaction by applying the following Equation 1:

$$Y_{ij}=\mu+A_i+B_j+A_i\times B_j+e_{ij} \quad (1)$$

where:

Y_{ij} = the observed value of the i aging time group effect and j cottonseed hull diets,

μ = mean value common to all observations,

A_i = fixed effect of aging time group,

B_j = fixed effect of cottonseed hull diets,

$A_i\times B_j$=interaction between aging time group and cottonseed hull diets, and

e_{ij} = the error term. Tukey's test was used to compare treatment means and they were considered to be significantly different when $p < 0.05$.

Results

There was no interaction ($p > 0.05$) among diets and meat aging time for any of the evaluated

variables. Thus, effects of diets and meat aging time were presented and discussed as principal effects.

There were no statistical differences ($p > 0.05$) for components of the carcass composition among diets (Table 4), presenting all diets similar percentages of muscle, fat, bone and other tissues.

Table 4. Carcass composition of bulls fed with cottonseed hull diets in high-concentrate system.

	Cottonseed hull diets (g kg^{-1} of DM)			SEM	p value
	CH21	CH27	CH33		
Muscle, %	65.0	65.4	63.3	2.30	0.24
Intermuscular fat, %	10.6	10.5	12.1	0.79	0.98
Subcutaneous fat, %	5.23	5.15	4.65	0.37	0.46
Total fat, %	15.8	15.7	16.7	0.95	0.93
Subcutaneous fat, mm	2.60	2.97	2.46	0.20	0.58
Bone, %	15.9	15.4	17.1	0.62	0.91
Other tissues, %	3.20	3.49	2.90	0.29	0.48

SEM: Standard error of means; CH21: cottonseed hull 210 g kg^{-1} on a DM basis; CH27: cottonseed hull 270 g kg^{-1} on a DM basis; CH33: cottonseed hull 330 g kg^{-1} on a DM basis.

The pH_{24h} results in the *LM* were similar ($p > 0.05$; Table 5) among the diets.

Meat from CH27 diet presented lower ($p = 0.02$; Table 5) moisture contents within the *LM*, while the total lipids were reduced ($p = 0.03$; Table 5) in meat from the CH33 diet. However, the ash, crude protein, and collagen contents (mg kg^{-1} of meat) of the *LM* were similar ($p > 0.05$) in meat from the bulls of the three diets (Table 5).

Table 5. Chemical composition of the *Longissimus* muscle of bulls fed with cottonseed hull diets in high-concentrate system.

	Cottonseed hull diets			SEM	p value
	CH21	CH27	CH33		
pH_{24h}	5.79	5.76	5.70	0.01	0.09
Moisture, %	71.7^{a}	71.1^{b}	71.7^{a}	0.10	0.02
Ashes, %	1.07	1.07	1.02	0.02	0.64
Crude protein, %	23.1	23.6	23.5	0.09	0.05
Total lipids, %	2.89^{a}	2.99^{a}	2.56^{b}	0.07	0.03
Collagen, mg g^{-1} of meat	1.31	1.28	1.26	0.01	0.30

a-b: Values with different letters in the same row were different by Tukey test ($p \leq 0.05$). SEM: Standard error of means; CH21: cottonseed hull 210 g kg^{-1} on a DM basis; CH27: cottonseed hull 270 g kg^{-1} on a DM basis; CH33: cottonseed hull 330 g kg^{-1} on a DM basis.

The drip and thawing losses did not change ($p > 0.05$; Table 6) in meat from the bulls fed with three diets. Likewise, the aging time did not change ($p > 0.05$; Table 6) the drip and thawing losses. On the other hand, the meat from CH21 diets at 24 hours presented with lower ($p = 0.004$; Table 6) cooking losses than other diets. However, at seven and 14 days, the cooking loss was similar among diets ($p > 0.05$; Table 6).

The diets did not affect ($p > 0.05$; Table 6) WBSF in *LM*. On the other hand, *LM* shear force was affected ($p = 0.001$; Table 6) by aging time. The increasing aging time reduced the WBSF by 75% in all diets.

The instrumental color was affected ($p = 0.04$; Figure 1) by diets and aging time. Diet did not change ($p > 0.05$) lightness (L★, Figure 1a), redness (a★, Figure 1b), and yellowness (b★, Figure 1c) values for all diets and at the four aging times studied, except for CH27 diet, which presented greater L★ ($p = 0.04$; Figure 1a) and b★ ($p = 0.001$; Figure 1c) values at 24 hours. However, the values observed at 14 days were similar to those observed at 24 hours. Thus, there was a positive quadratic behaviour for L★ values. Contrastingly, a★ values were greater at 24 hours and 14 days and lower at three and seven days. Thus, there was a negative quadratic behaviour for a★ values. Aging time days increased linearly ($p = 0.001$ the b★ values in the *LM*.

The lipid oxidation (TBARS) of *LM* was lower ($p = 0.001$; Figure 1d) in meat from the CH21 diet at 24 hours. However, at 3, 7and 14 days the values were similar ($p > 0.05$; Figure 1d) among the three diets. However, the TBARS values were influenced by aging time ($p = 0.001$; Figure 1d). The TBARS values increased linearly ($p < 0.05$; Figure 1d) with aging time of the *LM* of bulls fed all diets.

The fatty acid percentages were similar ($p > 0.05$) in the *LM* muscle from bulls fed with three diets (Table 7). Similarly, the saturated (SFA), monounsaturated (MUFA), and polyunsaturated fatty acids (PUFA) within *LM* were similar ($p > 0.05$; Table 7) among three diets. Similarly, amounts of *n*-6 and *n*-3 fatty acids were not influenced ($p > 0.05$; Table 7) by diets. The diets did not affect ($p > 0.05$; Table 7) the PUFA: SFA and *n*-6: *n*-3 ratios.

Table 6. Water holding capacity and Warner-Bratzler shear force within the *Longissimus* muscle of bulls fed with cottonseed hull diets in high-concentrate system with aging or no aging days.

	CH21			CH27			CH33			SEM	p value		
	24 hours	7 days	14 days	24 hours	7 days	14 days	24 hours	7 days	14 days		CH	A	CH x A
Drip loss, %	2.31	-	-	3.18	-	-	3.03	-	-	0.15	0.06	-	-
Thawing loss, %	8.63	10.7	9.75	11.2	9.60	8.77	8.17	8.98	9.46	0.47	0.77	0.99	0.52
Cooking loss, %	28.3^{a}	28.5	30.6	32.1^{b}	31.3	33.2	31.1^{b}	30.8	33.1	0.41	0.004	0.06	0.98
WBSF, kgf cm^{-2}	8.32^{B}	5.00^{A}	4.60^{A}	8.31^{B}	5.64^{A}	4.86^{A}	9.29^{B}	5.79^{A}	5.32^{A}	0.27	0.45	0.001	0.89

a-b: Values with different letters in the same row were different by Tukey test; A-C: Values with different letters in the same row were different by Tukey test to aging time; CH21: cottonseed hull 210 g kg^{-1} on a DM basis; CH27: cottonseed hull 270 g kg^{-1} on a DM basis; CH33: cottonseed hull 330 g kg^{-1} on a DM basis; 24 hours: no aging days; 7 days: aging seven days; 14 days: aging 14 days; SEM: Standard error of means; CH: cottonseed hull effects; A: aging time effects; CH x A: interaction cottonseed hull x aging time effects; WBSF: Warner-Bratzler shear force.

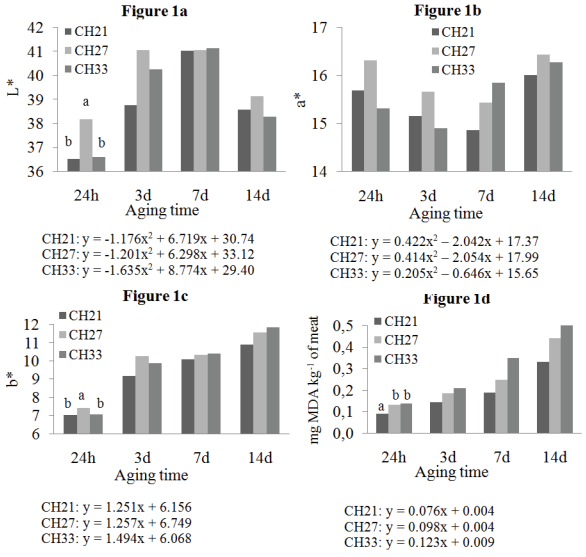

Figure 1. Lightness (L*), redness (a*), yellowness (b*) and TBARS (mg MDA kg^{-1} of raw meat) of the *Longissimus* muscle of bulls fed co-products from Brazilian agribusinesses in high-concentrate system with aging or no aging days.

Discussion

Percentages of muscle (64.6%), total fat (16.1%), bone (16.1%), and other tissues (3.2%) within the *LM* corroborated to compositions reported in other studies with crossbreed bulls (Maggioni et al., 2010). Muscle, fat, and bone compositions of the carcasses are influenced by the animal's breed; however, the fat percentage of the carcasses may be influenced by feed, feeding strategies, animal age, gender and crossbreeding (Campo et al., 2008; Warren et al., 2008). The subcutaneous fat (2.7 mm) presented with lower values than required by the market (3 – 6 mm), but no carcass was penalized by a reduced carcass fat distribution. The lower values that were observed were most likely related to the animal's utilized genetic group (½ Simmental – ½ Nellore). In general, the bulls from crossbreeding between Continental and Zebu breeds presented a low fat thickness (Prado et al., 2008a; 2008b; 2009a).

The observed pH_{24h} values (5.7) were considered to be normal pH for bulls with fat thicknesses less than 4.7 mm, in animals that were not stressed at slaughter time (María, Villarroel, Sañudo, Olleta, & Gebresenbet, 2003), and in young bulls that were finished in a feedlot.

The moisture (71.5%), ash (1.05%), and crude protein (23.4%) contents within the *LM* of bulls that were fed with cottonseed hull diets agreed with the characteristics expected of young bulls (Serra et al., 2004), Simmental vs. Nellore steers (Padre et al., 2007; Prado et al., 2008a; 2008b), and animals fed with Brazilian co-products (Eiras et al., 2014). The mean values of the total lipids observed in *LM* were considered to be below the values that are recommended (3%) by the English Health Department (HMSO, 1994). According to Pensel (1997), intramuscular fat concentrations below the maximum level (5%) are recommended to prevent coronary heart diseases. *LM* total lipid values of bulls that were fed with cottonseed hull diets in a high-concentrate system were similar to those of other studies (2-3%) in which bulls were finished in feedlots (Prado et al., 2008b; 2009a; Christensen et al., 2011). The cottonseed hull diets influenced the proportion of soybean hull pellets within the diets and, could be influenced the fiber fermentation within the rumen (Bach, Yoon, Stern, Jung, & Chester-Jones, 1999). According to the NRC (2000), the non-fiber carbohydrates (pectin) present with high digestibility values in rumen fermentation and demonstrate a high correlation with the formation of acetate fatty acid.

Table 7. Fatty acids composition of the *Longissimus* muscle of bulls fed with cottonseed hull diets in high-concentrate system.

Fatty acids, %	Cottonseed hull diets (g kg^{-1} of DM)			SEM	p value
	CH21	CH27	CH33		
SFA[1]	40.6	41.2	42.3	0.51	0.45
MUFA[2]	40.6	42.1	39.6	0.68	0.36
PUFA[3]	18.8	16.7	18.1	0.74	0.50
n-6	15.2	12.9	14.8	0.64	0.30
n-3	2.82	3.00	2.57	0.21	0.75
PUFA: SFA	0.47	0.41	0.43	0.02	0.47
n-6: n-3	5.55	5.32	5.93	0.41	0.84
Atherogenic index[4]	0.54	0.53	0.54	0.01	0.95
C 12:0	0.06	0.06	0.06	0.002	0.76
C 14:0	2.17	2.04	1.93	0.07	0.42
C 15:0	0.45	0.51	0.52	0.02	0.44
C 16:0	22.6	22.5	22.9	0.27	0.88
C 17:0	0.99	1.20	1.05	0.27	0.27
C 18:0	13.5	14.0	14.8	0.43	0.49
C 20:0	0.32	0.37	0.41	0.03	0.52
C 22:0	0.08	0.07	0.09	0.007	0.32
C 24:0	0.47	0.50	0.55	0.02	0.43
C 14:1 *n*-7	0.47	0.47	0.46	0.02	0.98
C 14:1 *n*-9	0.18	0.18	0.23	0.01	0.21
C 15:1 *n*-9	1.84	1.39	2.00	0.14	0.20
C 16:1 *n*-9	2.26	2.25	2.15	0.10	0.90
C 16:1 *n*-7	0.40	0.39	0.42	0.009	0.47
C 17:1 *n*-7	1.95	1.59	1.53	0.14	0.44
C 18:1 *n*-7	1.45	1.38	1.39	0.04	0.82
C 18:1 *n*-9	29.9	32.4	29.5	0.66	0.16
C 18:1 *trans*	1.95	1.88	1.76	0.16	0.90
C 20:1 *n*-9	0.19	0.15	0.16	0.01	0.61
C 18:2 *trans*	0.68	0.70	0.67	0.02	0.90
C 18:2 *n*-6	12.4	10.6	11.9	0.49	0.33
C 18:2 *c*-9 *t*-11	0.12	0.09	0.09	0.01	0.60
C 18:3 *n*-6	0.20	0.18	0.19	0.01	0.87
C 18:3 *n*-3	0.81	1.23	0.62	0.17	0.39
C 20:2 *n*-6	2.18	1.70	2.22	0.19	0.50
C 20:3 *n*-3	1.25	1.15	1.18	0.08	0.87
C 20:4 *n*-6	0.41	0.36	0.44	0.06	0.90
C 20:5 *n*-3	0.28	0.20	0.23	0.02	0.48
C 22:6 *n*-3	0.49	0.43	0.55	0.04	0.64

CH21: cottonseed hull 210 g kg^{-1} on a DM basis; CH27: cottonseed hull 270 g kg^{-1} on a DM basis; CH33: cottonseed hull 330 g kg^{-1} on a DM basis; [1]Saturated fatty acids; [2]Mono-unsaturated fatty acids; [3]Poly-unsaturated fatty acids; [4]Atherogenic index: (C14:0 x 4) + C16:0 / (MUFA +∑n-6 + ∑n-3).

Collagen content in the meat (1.3 mg g^{-1} of wet tissue) can be considered low (Serra et al., 2008). This low value is due to the animal's age at slaughter (16-mo). In general, young bulls present with low collagen content in the meat (Christensen et al., 2011). The increases in cottonseed hull within diets did not affect the collagen content within *LM*. The fiber content in the diets did not affect the drip loss, which was 2.9%. In general, the drip loss varies from 1 to 3% in bulls' carcasses (Frylinck, Strydom, Webb, & Toit, 2013). Thus, the drip loss that was observed in this study may be considered normal in bulls that are finished in feedlots and are slaughtered close to 500 kg of body weight (Waritthitham, Lambertz, Langholz, Wicke, & Gauly, 2010).

Thawing loss varied from 8 to 11%. The diets and aging time did not affect thawing loss. In general, meat from bulls that were finished in feedlots and fed with a high-concentrate diet presented with thawing losses between 9.4 and 12.4% (Eiras et al., 2014).

The cooking loss that was observed 24 hours after slaughter was lower in meat from bulls that were fed with the CH21 (28.3%) diet in comparison to meat from bulls that were fed other diets (31.5%). However, the cooking losses in meat that was aged for 7 and 14 days were similar among the three diets. Thus, in general, the fiber content in the cottonseed hull diets and the aging time did not affect cooking loss. The values that were observed in this study were close to those observed in meat from crossbred bulls that were slaughtered between carcass weights of 269 and 328 kg (Waritthitham et al., 2010).

A Warner-Bratzler shear force (WBSF) value for cooked meat above 6 kg cm^{-2} has been suggested as the threshold that separates tender and tough meat (Shackelford, Wheeler, & Koohmaraie, 1997). In the present study, WBSF of cooked samples varied from 8.6 (24 hours aging time) to 5.5 (7 aging days) and 5.0 kg (14 aging days). Therefore, the *LM* from all diets in the present study may be considered tender after seven days of aging when using this criterion. Therefore, the meat aging time decreased the WBSF and was shown to tenderize the meat, as evaluated by several authors (Frylinck et al., 2013; Hopkins, Allingham, Colgrave, & Van de Ven, 2013). Only meat from the 24 hours aging time, which was included in the study, had WBSF values above 8.0 kg and hence, could be considered extremely tough. Conversely, the diets did not affect the meat WBSF.

The cottonseed hull diets did not affect the lightness (L⋆), redness (a⋆), and yellowness (b⋆) of the *LM* by aging time. However, CH27 presented greater L⋆ (38.2 points) and b⋆ (7.41 points) at the 24 hours aging time. According to Page, Wulf, and Schwotzer (2001), the *LM* color is influenced by the pH, water activity, and fat composition of the muscle. In this study, the CH27 presented smaller moisture (71.1%) percentages and greater lipid (2.99%) values in the *LM* than other diets. In general, until the 7th day of aging, the L⋆ increased while the redness (a⋆) was reduced in all diets. However, at the 14th aging day, the increasing trend of L⋆ and a⋆ in the *LM* were altered by the myoglobin oxidation (Page, Wulf, & Schwotzer, 2001). The pattern of increasing metmyoglobin formation with aging time was also observed in the evolution of b⋆ values in the *LM*.

The lipid oxidation (TBARS) was affected by diets with 24 hours aging time. Thus, the extension of lipid oxidation with CH21 was smaller for all aging times. CH21 presented with smaller cottonseed hulls, while there was an increased proportion of the soybean hull pellets. According to Brouns, Van Nieuwenhoven, Jeukendrup, and Lichtenbelt (2002), the isoflavonoids that are present in soybean products may reduce the free radical contents and have antioxidant properties in human health. King, Mano, and Head (1998) observed that lower isoflavonoids values in the milk of cows that were fed silage did not elicit a biological response in humans. However, Lundh, Pettersson, & Martinsson (1990) observed significant plasma values of isoflavonoids in cows that were on pasture. Therefore, the increasing soybean hull pellets could be reduced by the extension of the *LM* lipid oxidation of CH21.

The fiber content in the cottonseed hull diets did not affect the individual fatty acid composition within the *LM*. However, the composition of saturated (SFA) and polyunsaturated (PUFA) fatty acids was affected. The SFA (41%) percentages were reduced in the *LM* of all diets, whereas PUFA (18%) content was increased when comparing several studies with similar conditions. Normally, SFA in *LM* varies between 48-50% for ½ European - ½ Nellore bulls that are finished in feedlots (Maggioni et al., 2010) and in bulls with 3 or 4 mm of fat thickness (Albertí et al., 2014). However, PUFA presents with values between 3.9-10.9% for crossbred bulls and 6.5-8.9% values for animals in feedlot systems (Rotta et al., 2009). However, Simmental bulls presents with lower SFA means and high PUFA values (Padre et al., 2007; Prado et al., 2009b). Thus, the reduction in SFA and increase in PUFA could be related to animal crossbreeding. Conversely, the fiber contents in the diets may influence volatile fatty acids in ruminal fermentation by increasing the acetate acid

formation (Bach et al., 1999). According to Pantoja, Firkins, Eastridge, and Hull (1994), the fiber sources that were utilized in this experiment could be utilized at adequate levels for fatty acid depositions in milk and most likely in the meat of bulls. Therefore, the elevated insoluble carbohydrate contents in the diets increase the PUFA values (Prado et al., 2009a; 2009b) while decreasing the SFA means (Rotta et al., 2014) and changing the PUFA: SFA ratio (Realini, Duckett, Brito, Rizza, & Mattos, 2004).

In general, meat from bulls that are finished in feedlots and fed with high energy density diets present with PUFA: SFA ratios between 0.10 and 0.20 (Rotta et al., 2009; 2014). Conversely, the observed PUFA: SFA(0.44) in meat in this study is in accord with Human Health Recommendations (0.40) (HMSO, 1994). Thus, the fiber sources in the diets (soybean hull pellets and cottonseed hulls) from Brazilian co-products improved the PUFA: SFA ratio of meat, as observed in the meat from bulls that were finished in pasture systems (Padre et al., 2007; Realini et al., 2004), while the observed meat quality was like that of bulls finished in feedlot systems.

Conclusion

The carcass characteristics and meat quality of bulls finished in feedlot and that were fed with diets composed by cottonseed hull in a high-concentrate system met the nutrition of bulls. Likewise, the lean meat production and the aging time effects on meat quality were obtained according to market demands. Thus, the use of co-products from cottonseed hull until 330 g kg^{-1}on a DM basis could be useful strategies in high-concentrate systems to improve the meat quality and lean beef production.

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